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Indian Standard

COATING MATERIALS (METALS, ALLOYS AND DIELECTRICS) USED IN OPTICAL INSTRUMENT INDUSTRY

UDC 666·1·056 : 681·4

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MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110001

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Indian Standard

COATING MATERIALS (METALS, ALLOYS AND DIELECTRICS) USED IN OPTICAL INSTRUMENT INDUSTRY

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(*Continued on page* 2)

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Indian Standard

COATING MATERIALS (METALS, ALLOYS AND DIELECTRICS) USED IN OPTICAL INSTRUMENT INDUSTRY

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 29 November, 1973, after the draft finalized by the Optical and Mathematical Instruments Sectional Committee had been approved by the Mechanical Engineering Division Council.

0.2 This standard highlights the various details about the coating materials (metals, alloys and dielectrics) used in optical instrument industry in order to facilitate comparison and selection of proper coating materials for particular use. This standard further highlights the various optical, physical and chemical properties of metals, alloys and dielectrics used as coating materials (massive as well as evaporated) in optical instrument industry.

1. SCOPE

1.1 This standard covers the optical, physical and chemical characteristics of coating materials (massive as well as evaporated) including metals, alloys and dielectrics used in optical instrument industry in order to facilitate their comparison and selection for particular use (*see* Table 1).

TABLE 1 CHARACTERISTICS OF COATING MATERIALS

(Clause

Sl No.	Substance	Symbol/ Composition	Massive Material				
			Optical			Physical	
			Complex refractive index		Reflectance	Melting point °C	Density g/cm³ at 20°C
			Refractive Index at 0·589 μm	*Index of Absorption Region of Transparency**			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Metals							
1	Aluminium	Al	1·44	Varies from 2·85 to 3·92 for $\lambda=431$ to 0·657 μm	Varies from 73% to 97·3% for $\lambda=1$ to 12 μm	660	2·70
2	Antimony	Sb	3·04	—	a) 53% for $\lambda=0{\cdot}6$ μm b) Varies from 55% to 72% for $\lambda=1$ to 9 μm	630	6·68
3	Barium	Ba	—	—	—	717	3·50
4	Beryllium	Be	—	—	—	1 284	1·85
5	Bismuth	Bi	a) 1·78 b) 4·5 at 1·0	a) Varies from 1·01 to 1·66 for $\lambda=0{\cdot}257$ to 0·398 μm b) Varies from 1·64 to 1·58 for $\lambda=0{\cdot}441$ to 0·668 μm	Varies from 71·7% to 81·6% for $\lambda=3$ μm	271	9·78
6	Boron	B	2·5 at 0·579 μ	—	—	2 000 to 2 080	2·5
7	Cadmium	Cd	1·13	Varies from 4·43 to 4·05 for $\lambda=0{\cdot}589$ μm	Varies from 70·8% to 98·2% for $\lambda=1{\cdot}06$ to 12·03 μm	321	8·65
8	Cesium	Cs	0·32	Varies from 2·37 to 4·34 for $\lambda=0{\cdot}455$ to 0·68 μm	Varies from 37·2% to 63·2% for $\lambda=0{\cdot}455$ to 0·68 μm	29	1·87

*For dielectric materials.

†Resistance to abrasion of the evaporated material on glass substrate is grouped in three categories as explained below:

a) *Poor* — Removable on rubbing with a soft cloth.
b) *Good* — Withstand polishing and cleaning.
c) *Exceptionally Good* — Not removable by scratching with a steel pin.

FOR USE IN OPTICAL INSTRUMENT INDUSTRY

1.1)

EVAPORATED MATERIAL				CHEMICAL DURABILITY	DEPOSITION TECHNIQUE	REPORTED APPLICATIONS
Optical			Physical Resistance to Abrasion on Glass Substrate†			
Complex refractive index at 0·546/0·589 µm*		Reflectance at 0·546 µm region of transparency*				
Refractive Index	*Extinction Coefficient*					
(9)	(10)	(11)	(12)	(13)	(14)	(15)
0·02	5·99	91·6	Good	Produces film which does not tarnish quickly; excellent resistance to atmospheric corrosion except near coastal areas; dissolved by alkalis & hydrochloric acid	Vacuum evaporation (tungsten filament); most difficult to sputter	Optical mirrors for visible; ultraviolet and infra-red regions; ultraviolet and vacuum ultraviolet interference filters; beam splitters; drawn and cast aluminium used in vacuum chambers
3·4 at 1·0 µm	4·1 at 1·0 µm	62·2 at 1·0 µm	—	Oxidized on heating strongly in air; attacked by acids	Vacuum evaporation (tungsten); can be sputtered easily	—
0·89	1·51	39·2	—	Oxidized in contact with air	Vacuum evaporation (tungsten)	Better material; much employed (mixed with strontium) as cathode material
2·66	2·36	43·9	—	Does not corrode easily; an oxidized film protects it from further oxidation	Vacuum evaporation (electron beam, tungsten basket, tantalum spirals)	Lenard window in X-ray tube; film on glass gives high reflectivity in ultraviolet region
—	—	—	Good, when oxidized to bismuth oxide	Oxidized on heating strongly in air; attacked by oxidizing acids only	Vacuum evaporation (tungsten); can be reactively sputtered to form bismuth oxide	Bismuth oxide film is used as beam splitters; two-layer anti-reflection coating and heat reflecting filters in combination with gold film
—	—	—	—	Soluble in nitric and sulphuric acids	Vacuum evaporation (electron beam)	Coating of boron is used on silicon crystals of solar batteries
—	—	—	—	Oxidized on heating strongly in air; attacked by acids	Vacuum evaporation (tungsten); can be sputtered easily	Used for special photocell cathodes
0·278	0·950	56·1	—	Oxidized very rapidly at atmospheric pressure; attacked by acids	Vacuum evaporation	Used as an evaporated layer on oxidized silver layer in vacuum to form a photosensitive surface

(*Continued*)

TABLE 1 CHARACTERISTICS OF COATING MATERIALS

Sl No.	Substance	Symbol/ Composition	Massive Material				
			Optical			Physical	
			Complex refractive index		Reflectance	Melting point °C	Density g/cm^3 at 20°C
			Refractive Index at 0·589 μm	*Index of Absorption Region of Transparency**			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
9	Chromium	Cr	2·97 at 0·579 μ	a) Varies from 2·25 to 2·13 for λ=0·257 to 0·415 μm b) Varies from 1·88 to 1·31 for λ=0·444 to 0·608 μm Spectral emissivity for λ=0·65 μm is 0·34	a) Varies from 33% to 41% for λ=0·188 to 0·357 μm b) Varies from 55% to 56% for λ=0·50 to 0·70 μm c) Varies from 57% to 93% for λ=1 to 10 m	1 900	7·14
10	Cobalt	Co	2·35 at 0·650 μ	a) Varies from 1·30 to 1·83 for λ=0·2 310 to 0·420 μm b) Varies from 1·87 to 1·78 for λ=0·44 to 0·68 μm Spectral emissivity for λ=0·65 μm is 0·36	a) Varies from 33% to 54% for λ=0·188 to 0·357 μm b) Varies from 67·5% to 96·6% for λ= 1·06 to 12·03 μm	1 478	8·71
11	Copper	Cu	0·64	a) Varies from 1·05 to 1·50 for λ=0·231 to 0·395 μm b) Varies from 1·90 to 5·77 for λ=0·45 to 0·66 μm Spectral emissivity for λ=0·65 μm is 0·10	a) Varies from 25·92% to 32·7% for λ= 0·251 to 0·420 μm b) Varies from 37·0% to 88·6% for λ= 0·45 to 0·8 μm c) Varies from 90·1% to 97·9% for λ= 1 to 14 μm	1 083	8·93
12	Gallium	Ga	—	—	—	29·78	5·91
13	Germanium	Ge	5·70 at 0·600 μ	—	—	959	5·36
14	Gold	Au	0·42 at 0·580 μ	Varies from 1·13 to 13·60 for λ=0·40 to 0·70 μm Spectral emissivity for λ=0·65 μm is 0·14	—	1 063	19·3
15	Iridium	Ir	2·13 at 0·579 μ	Varies from 2·28 to 2·10 for λ=0·578 to 0·66 μm Spectral emissivity for λ=0·65 μm is 0·30	Varies from 79·4% to 96·1% for λ=1 to 12·03 μm	2 454	22·42
16	Iron	Fe	2·36	Spectral emissivity for λ=0·66 μm is 0·39	a) Varies from 55% to 61·5% for λ=0·5 to 0·8 μm b) Varies from 65·0% to 93·8% for λ= 1 to 9 μm	1 535	7·86

*For dielectric materials.

†Resistance to abrasion of the evaporated material on glass substrate is grouped in three categories as explained below:

a) *Poor* — Removable on rubbing with a soft cloth.
b) *Good* — Withstand polishing and cleaning.
c) *Exceptionally Good* — Not removable by scratching with a steel pin.

FOR USE IN OPTICAL INSTRUMENT INDUSTRY — *Contd*

EVAPORATED MATERIAL				CHEMICAL DURABILITY	DEPOSITION TECHNIQUE	REPORTED APPLICATIONS
Optical			Physical Resistance to Abrasion on Glass Substrate†			
Complex refractive index at 0·546/0·589 μm*		Reflectance at 0·546 μm region of transparency*				
Refractive Index	*Extinction Coefficient*					
(9)	(10)	(11)	(12)	(13)	(14)	(15)
2·48	2·30	43·0	Exceptionally good	Does not react with alkalis and acids but with great difficulty with hydrochloric acid plus zinc dust	Vacuum evaporation (tungsten); difficult to sputter	Base layer for aluminised mirror to increase the adhesion; shadowing for optical microscopy; graticulation work; beam splitters
—	—	—	—	Oxidized on heating strongly in air; attacked by acids	Sputtered readily; vacuum evaporation (electron beam, columbium)	—
0·756 at 0·550 μm	2·462 at 0·550 μm	66·9 at 0·550 μm	Poor	Oxide formed at relatively low temperature but is decomposed at higher temperature; attacked by oxidizing acids only	Vacuum evaporation (molybdenum boat); readily sputtered	Highly reflecting film in infrared region; protection of back surface mirrors
—	—	—	—	Soluble in acid alkali, oxidized on heating strongly in air	—	Electron carrier in solar batteries and in silicon rectifiers
3·47	1·40	36·7	Good	Soluble in hot sulphuric acid	Vacuum evaporation (electron beam, tantalum, molybdenum)	Cold mirror in combination with dielectric coatings
0·331 at 0·550 μm	2·324 at 0·550 μm	81·5	Poor	Does not tarnish; attacked by concentrated nitric and hydrochloric acids	Vacuum evaporation (electron beam, molybdenum)	Aircraft windows and heat reflecting filters in combination with bismuth oxide film; useful as photo cathode also
4·26 at 1·16 μm for sputtered material	6·86 at 1·16 μm for sputtered material	74·6 for sputtered material	—	Attacked by hot nitric and hydrochloric acids	Vacuum evaporation (electron beam)	—
—	—	—	Exceptionally good for oxidized film	Oxidized on heating strongly in air; attacked by acids	Vacuum evaporation (electron beam, tungsten helical coil); can also be sputtered	Oxidized film of iron is used as beam splitters and in tinting the ophthalmic glasses

(*Continued*)

TABLE 1 CHARACTERISTICS OF COATING MATERIALS

Sl No.	Substance	Symbol/ Composition	Massive Material				
			Optical			Physical	
			Complex refractive index		Reflectance	Melting point °C	Density g/cm³ at 20°C
			Refractive Index at 0·589 µm	*Index of Absorption Region of Transparency**			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
17	Lead	Pb	2·01	2·10 for λ=0·578 µm	Varies from 74·8% to 96·5% for λ=1·06 to 12·03 µm	327·3	11·34
18	Lithium	Li	3·16	—	—	180·55	0·534
19	Magnesium	Mg	0·37	Varies from 11·82 to 11·5 for λ=0·589 to 0·63 µm	a) Varies from 13·0% to 45% for λ=0·188 to 0·357 µm b) Varies from 70% to 73% for λ=0·5 to 0·6 µm c) Varies from 74% to 93% for λ=1 to 9 µm	651	1·74
20	Manganese	Mn	2·26	Varies from 1·79 to 1·83 for λ=0·257 to 0·397 µm Spectral emissivity for λ=0·65 µm is 0·59	—	1 244	7·3
21	Nickel	Ni	1·79	Varies from 1·79 to 1·97 for λ=0·42 to 0·7 µm Spectral emissivity for λ=0·65 µm is 0·36	—	1 455	8·9
22	Palladium	Pd	1·62 at 0·578µ	2·10 for λ=0·578 Spectral emissivity for λ=0·65 µm is 0·33	Varies from 74·8% to 96·5% for λ= 1·06 to 12·03 µm	1 555	12·0
23	Platinum	Pt	2·06	Varies from 2·08 to 2·11 for λ=0·439 to 0·704 µm Spectral emissivity is 0·30 for λ=0·66 µm	a) Varies from 35% to 51% for λ= 0·188 to 0·357 µm b) Varies from 95·4% to 96·4% for λ=9 to 14 µm	1 774	21·45

*For dielectric materials.

†Resistance to abrasion of the evaporated material on glass substrate is grouped in three categories as explained below:

a) *Poor* — Removable on rubbing with a soft cloth.
b) *Good* — Withstand polishing and cleaning.
c) *Exceptionally Good* — Not removable by scratching with a steel pin.

FOR USE IN OPTICAL INSTRUMENT INDUSTRY — *Contd*

EVAPORATED MATERIAL				CHEMICAL DURABILITY	DEPOSITION TECHNIQUE	REPORTED APPLICATIONS
Optical			Physical Resistance to Abrasion on Glass Substrate†			
Complex refractive index at 0·546/0·589 µm*		Reflectance at 0·546 µm region of transparency*				
Refractive Index	*Extinction Coefficient*					
(9)	(10)	(11)	(12)	(13)	(14)	(15)
—	—	—	—	Oxidized on heating strongly in air; very resistant to corrosion; soluble in nitric acid	Vacuum evaporation; can be sputtered	Thick lead in wires to electrodes of transmitting values
—	—	—	—	Soluble in acids	Vacuum evaporation (electron beam); one of the difficult metal to sputter	—
0·57	3·47	84·3	—	Good resistance to atmospheric corrosion; oxidized on heating in air, not affected by alkalis but by salt solution; readily attacked by acids	Vacuum evaporation (tungsten); most difficult to sputter	Base layer for aluminium mirrors to increase the adhesion properties
2·46	3·07	54·0	—	Oxidized on heating strongly in air; attacked by acids	Vacuum evaporation (electron beam, tungsten); can be sputtered	—
2·63 at 1·12 µm	4·28 at 1·12 µm	66·6 at 1·12 µm	—	Excellent resistance to atmospheric corrosion and to most acids except nitric acid; oxidised on heating strongly in air	Vacuum evaporation (electron beam, tungsten heavy gauze helical coil); can be sputtered	—
2·3	2·7	49·4	—	Highly resistant to atmospheric corrosion and acids; dissolves in aqua regia	Vacuum evaporation (electron beam, tungsten helical coil); can be readily sputtered	—
3·42 at 1·0 µm for sputtered film	6·3 at 1·0 µm for sputtered film	86·9 at 1·0 µm for sputtered film	Exceptionally good	Inert to all acids except aqua regia	Vacuum evaporation (electron beam, multi-strand tungsten filament with platinum wire twisted together); can be sputtered	Used in the manufacture of high grade optical graticules; commonly used where minimum corrosion is desirable

(*Continued*)

TABLE 1 CHARACTERISTICS OF COATING MATERIALS

SL NO.	SUBSTANCE	SYMBOL/ COMPOSITION	MASSIVE MATERIAL				
			Optical			Physical	
			Complex refractive index		Reflectance	Melting point °C	Density g/cm³ at 20°C
			Refractive Index at 0·589 μm	*Index of Absorption Region of Transparency**			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
24	Potassium	K	0·068	Varies from 14·3 to 26·8 for λ=0·472 to 0·665 μm	a) Varies from 10·6 to 79% for λ=0·254 to 0·405 μm b) Varies from 88% to 92·5% for λ=0·436 μm	63	0·86
25	Rhodium	Rh	1·54 at 0·579 μ	3·0 and 2·94 for λ= 0·578 and 0·660 μm respectively Spectral emissivity for λ=0·65 μm is 0·24	a) Varies from 78% to 81% for λ=0·5 to 0·8 μm b) Varies from 84% to 94·5% for λ=1 to 9 μm	1 967	12·5
26	Rubidium	Rb	0·131	—	—	38	1·53
27	Selenium	Se	2·85	a) Varies from 0·725 to 0·426 for λ=0·257 to 0·398 μm b) Varies from 0·359 to 0·161 for λ=0·441 to 0·668 μm	—	217	4·80
28	Silicon	Si	4·18	a) Varies from 0·12 to 114 for λ=0·578 to 0·589 μm b) 0·095 for λ=1 to 2·25 μm Spectral emissivity for λ=0·65 μm is 0·64	a) Varies from 34% to 29% for λ=0·5 to 0·8 μm b) 28% for λ=1 to 9 μm	1 410	2·4
29	Silver	Ag	0·18	a) Varies from 75 to 12·3 for λ=0·226 to 0·395 μm b) Varies from 14·5 to 19·5 for λ=0·45 to 0·63 μm Spectral emissivity for λ=0·65 μm is 0·07	a) Varies from 88% to 95% for λ=0·45 to 0·8 μm b) Varies from 96% to 98·8 for λ=0·9 to 14 μm	961	10·5
30	Strontium	Sr	—	—	—	771	2·6

*For dielectric materials.

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- a) *Poor* — Removable on rubbing with a soft cloth.
- b) *Good* — Withstand polishing and cleaning.
- c) *Exceptionally Good* — Not removable by scratching with a steel pin.

FOR USE IN OPTICAL INSTRUMENT INDUSTRY — *Contd*

EVAPORATED MATERIAL				CHEMICAL DURABILITY	DEPOSITION TECHNIQUE	REPORTED APPLICATIONS
Optical			Physical Resistance to Abrasion on Glass Substrate†			
Complex refractive index at 0·546/0·589 µm*		Reflectance at 0·546 µm region of transparency*				
Refractive Index	*Extinction Coefficient*					
(9)	(10)	(11)	(12)	(13)	(14)	(15)
0·091	1·42	88·6	—	React strongly with air at normal temperature soluble in acids; to be kept in kerosine	Vacuum evaporation	Used in manufacture of special types of photocells. Potassium oxide photocell has a high green and blue sensitivity but is sensitive in the infra-red region
1·62	4·63	77·1	Exceptionally good, extremely hard and adhesive if deposited in a mercury diffusion pump, system	Good resistant to sea atmosphere and tropical conditions; oxide forms on heating at low temperature, attacked by oxidizing acids only	Sublimation from electro deposited rhodium on tungsten spiral; vacuum evaporation (electron beam)	Durable front surface mirrors; beam splitters
0·157	1·05	74·2	—	Easily oxidized in air; attacked by acids	Vacuum evaporation; can be readily sputtered	Used in rubidium oxide photocell giving a spectral sensitivity approximate to that of human eye
3·05 at 0·55 µm for amorphous film	0·28 at 0·55 µm for amorphous film	26·0 at 0·55 µm for amorphous film	—	Oxidized on heating strongly in air; attacked by acids	Vacuum evaporation (molybdenum boat)	Photo-voltaic cells and rectifier plate
3·5	—	—	—	—	Vacuum evaporation (electron beam, beryllium oxide crucible); difficult to prepare film free from silicon monoxide	—
0·055 at 0·55 µm	3·32 at 0·55 µm	98·2 at 0·55 µm	Poor	Tarnishes quickly when left expose to air; attacked by oxidizing acids only	Vacuum evaporation (molybdenum tantalum boat)	Best reflector for visible as well as infra-red regions; interference filters in combination with dielectric films; fabry-perot reflecting plates
0·63	1·99	61·9	—	Easily oxidized in air; attacked by acids	Vacuum evaporation (tungsten, tantalum)	Its oxide mixed with barium oxide is used to form the standard thermionic cathode coating

(Continued)

TABLE 1 CHARACTERISTICS OF COATING MATERIALS

SL No.	SUBSTANCE	SYMBOL/ COMPOSITION	MASSIVE MATERIAL				
			Optical			Physical	
			Complex refractive index		Reflectance	Melting point °C	Density g/cm^3 at 20°C
			Refractive Index at 0·589 µm	*Index of Absorption Region of Transparency**			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
31	Tellurium	Te	a) 4·9 at 6·0 µ b) 1·0 at 0·589 µ	—	a) Varies from 21% to 41% for λ=0·188 to 0·357 µm b) 49% and 48% for λ=0·60 µm and 0·80 µm c) Varies from 49·5% to 78% for λ=1·2 to 9·0 µm	452	6·24
32	Thallium	Tl	—	—	—	303·6	11·85
33	Thorium	Th	—	Spectral emissivity is 0·36 for λ=0·65 µm	—	1 695	11·0
34	Tin	Sn	1·48	a) Varies from 2·98 to 2·82 for λ=0·257 to 0·398 µm b) Varies from 3·55 to 3·53 for λ=0·425 to 0·668 µm	Varies from 54% to 86·9% for λ=1·06 to 12·03 µm	232	6·55
35	Titanium	Ti	—	Spectral emissivity for λ=0·65 µm is 0·63	—	1 727	4·5
36	Uranium	U	—	Spectral emissivity is 0·55 for λ=0·65 µm	—	1 133	18·90 at 25°C
37	Vanadium	V	3·03 at 0·579 µ	1·16 for λ=578 µ Spectral emissivity is 0·35 for λ=0·65 µm	a) Varies from 57% to 78·8% for λ=50 to 4 µm b) Varies from 85% to 92% for λ=6 to 9 µm	1 917	5·87

*For dielectric materials.

†Resistance to abrasion of the evaporated material on glass substrate is grouped in three categories as explained below:
- a) *Poor* — Removable on rubbing with a soft cloth.
- b) *Good* — Withstand polishing and cleaning.
- c) *Exceptionally Good* — Not removable by scratching with a steel pin.

FOR USE IN OPTICAL INSTRUMENT INDUSTRY — *Contd*

EVAPORATED MATERIAL				CHEMICAL DURABILITY	DEPOSITION TECHNIQUE	REPORTED APPLICATIONS
Optical			Physical Resistance to Abrasion on Glass Substrate†			
Complex refractive index at 0·546/0·589 μm*		Reflectance at 0·546 μm region of transparency*				
Refractive Index	*Extinction Coefficient*					
(9)	(10)	(11)	(12)	(13)	(14)	(15)
—	—	—	—	Soluble in oxidizing acids	Vacuum evaporation (tantalum boat); can also be sputtered	Fabrication of selenium photocells
—	—	—	—	Soluble in nitric and sulphuric acids; oxidized on heating strongly in air	Can be sputtered	—
—	—	—	—	Soluble in hydrochloric and sulphuric acids; oxidized on heating in air	—	Mixture of thorium with tungsten gives thoriated tungsten filament which emits electrons more efficiently when heated than pure tungsten
—	—	—	Exceptionally good (for heat oxidized sputtered tin oxide film)	Tin oxide film attacked by alkalis	Reactively sputtered in an oxygen and inert gas atmosphere at 10^{-4} torr	Transparent heating elements and antistatic coatings on glass in the form of tin oxide
2·52	3·33	57·0	Exceptionally good	Oxidized on heating in air; attacked by acids	Vacuum evaporation (electron beam, tungsten conical basket with titanium wire twisted together)	Neutral film; titanium dioxide film is used as durable beam splitters; multilayer antireflection and highly reflecting coatings
—	—	—	—	Soluble in acids	—	Used as a cathode to photo electric tubes responsive to ultra violet radiations in atomic applications
—	—	—	—	Insoluble in alkalis and hydrochloric acid; soluble in oxidizing acids; oxidized on heating in air	Vacuum evaporation (electron beam, tungsten molybdenum)	—

(*Continued*)

TABLE 1 CHARACTERISTICS OF COATING MATERIALS

Sl No.	Substance	Symbol/ Composition	Massive Material				
			Optical			Physical	
			Complex refractive index		Reflectance	Melting point °C	Density g/cm^3 at 20°C
			Refractive Index at 0·589 µm	*Index of Absorption Region of Transparency**			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
38	Zinc	Zn	2·72	a) Varies from 1·10 to 3·45 for λ=0·257 to 0·398 µm b) Varies from 3·4 to 1·94 for λ=0·441 to 668 µm	a) Varies from 54·0% to 61·5% for λ= 0·45 to 0·80 µm b) Varies from 55·5% to 98·3% for λ= 0·90 to 12 µm	419·5	7·14
39	Zirconium	Zr	—	Spectral emissivity is 0·426 for λ=0·65 µm	—	1 852±10	6·4
Alloys							
40	Chromel	90% Ni 10% Cr	—	a) At transmission above 10% the films are closely neutral throughout the visible spectrum, but below the transmission is more selective for red light b) Spectral emissivity for λ=0·65 µm is 0·35	—	—	—
41	Inconel	76% Ni 15% Cr 9% Fe	—	Neutral transmission in the region 0·4 to 0·12 µm	—	—	—
42	Kanthal	65-75% Fe 25-30% Cr 5% Al	—	—	—	—	—
43	Nichrome	80% Ni 20% Cr	—	Spectral emissivity is 0·35 for λ=0·65 µm	—	—	8·36
Dielectrics							
44	Aluminium oxide	Al_2O_3	—	Spectral emissivity: Probable value for oxide formed on smooth metal is 0·30 for range of observed value 0·22 to 0·40 µm	—	2 050	3·5 to 3·9

*For dielectric materials.

†Resistance to abrasion of the evaporated material on glass substrate is grouped in three categories as explained below:
a) *Poor* — Removable on rubbing with a soft cloth.
b) *Good* — Withstand polishing and cleaning.
c) *Exceptionally Good* — Not removable by scratching with a steel pin.

FOR USE IN OPTICAL INSTRUMENT INDUSTRY — *Contd*

EVAPORATED MATERIAL				CHEMICAL DURABILITY	DEPOSITION TECHNIQUE	REPORTED APPLICATIONS
Optical			Physical Resistance to Abrasion on Glass Substrate†			
Complex refractive index at 0·546/0·589 μm*		Reflectance at 0·546 μm region of transparency*				
Refractive Index	*Extinction Coefficient*					
(9)	(10)	(11)	(12)	(13)	(14)	(15)
—	—	—	—	Oxidized on heating strongly in air; soluble virtually in all acids; dissolves in hot alkalis	Vacuum evaporation (tungsten or molybdenum); can also be sputtered	—
—	—	—	—	Soluble in hydrofluoric acid; oxidized on heating in air	Vacuum evaporation (electron beam)	As a better material used for high intensity electric lamp filament; grid wires and plates in vacuum tubes
—	—	At transmission above 10% the film is closely neutral throughout the visible spectrum but below the transmission is more selective for red light	—	—	Vacuum evaporation (electron beam)	Transmission filters of uniform or graded optical density
—	—	Neutral transmission in the region 0·40 to 1·2 μm	Exceptionally good	—	Vacuum evaporation (electron beam, tungsten helical filament)	Neutral transmission filters covering a range of optical densities
—	—	—	—	—	—	Graticulation work
—	—	—	Exceptionally good	—	Vacuum evaporation (electron beam, tungsten helical filament)	Base coatings on glass and ceramic for improving the adhesion of evaporated copper film
1·62 for anodised film at 0·6 μm 1·78 for reactively sputtered film	—	—	Good	Slightly soluble in acids	Vacuum evaporation (electron beam); anodic oxidation of aluminium film; reactively sputtered metal oxide film	Protection of aluminium mirrors specimen supports for electron difraction multilayers and antireflection coatings

(*Continued*)

TABLE 1 CHARACTERISTICS OF COATING MATERIALS

Sl No.	Substance	Symbol/ Composition	Massive Material				
			Optical			Physical	
			Complex refractive index		Reflectance	Melting point °C	Density g/cm^3 at 20°C
			Refractive Index at 0·589 μm	*Index of Absorption Region of Transparency**			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
45	Antimony trioxide	Sb_2O_3	—	—	—	656	5·2
46	Antimony trisulphide	Sb_2S_3	4·3	Range of transparency from 500 nm to 10 μm (nm=10^{-9}m)	Reflectivity: a) Varies from 52% to 60% for λ=0·24 to 0·35 μm b) Varies from 54% to 44% for λ=0·4 to 0·7 μm c) Varies from 40% to 30% for λ=0·1 to 13 μm	550	4·64
47	Barium oxide	BaO	—	—	—	1 923	—
48	Beryllium oxide	BeO	—	Spectral emissivity: Probable value 0·35 for range 0·07 to 0·37 μm	—	2 530±30	3·01
49	Bismuth oxide	Bi_2O_3	—	—	—	817	8·9
50	Cadmium oxide	CdO	—	—	—	>1 426 (decomposes)	6·95
51	Cadmium sulphide	CdS	2·52	Range of transparency: From 520 nm to >14 μm	—	1 750	4·82
52	Cadmium telluride	CdTe	2·6 in near infra-red	—	—	—	—

*For dielectric materials.

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a) *Poor* — Removable on rubbing with a soft cloth.
b) *Good* — Withstand polishing and cleaning.
c) *Exceptionally Good* — Not removable by scratching with a steel pin.

FOR USE IN OPTICAL INSTRUMENT INDUSTRY — *Contd*

EVAPORATED MATERIAL				CHEMICAL DURABILITY	DEPOSITION TECHNIQUE	REPORTED APPLICATIONS
Optical			Physical Resistance to Abrasion on Glass Substrate†			
Complex refractive index at 0·546/0·589 µm*		Reflectance at 0·546 µm region of transparency*				
Refractive Index	*Extinction Coefficient*					
(9)	(10)	(11)	(12)	(13)	(14)	(15)
1·85 for reactively sputtered film; 2·04 at 0·546 µm for evaporated film	—	0·3 to >1·0 µm	—	Soluble in hydrochloric acid and potassium hydroxide	Vacuum evaporation (molybdenum boat, platinum); metal oxide film prepared by baking, in air, an evaporated lower oxide deposit	—
3·01 at 0·623 µm; 2·5 at 10·0 µ	—	0·5 to 10·0	Poor	Soluble in alkalis	Vacuum evaporation (molybdenum)	Evaporated films are transparent in the infra-red and highly absorbing below 0·6 µm; beam splitter; multilayers
—	—	—	—	—	Vacuum evaportion (platinum)	—
1·719	—	—	—	Soluble in concentrated sulphuric acid	—	—
2·45 for reactively sputtered film	—	—	Good	Attacked by acids	Reactive sputtering of bismuth in oxygen and argon atmosphere at 5×10^{-4} torr; vacuum evaporation (platinum)	Beam splitter, base coating for gold film used as transparent electrically conducting air craft windows and heat reflecting filters
2·06 for reactively sputtered film	—	—	Poor	Attacked by acids and water	Reactive sputtering of cadmium in oxygen and argon atmosphere at 5×10^{-4} torr	Transparent electrically conducting window glass for aircrafts and automobiles; electrodes on selenium photocells
2·42; 2·6 at 0·6 µm and 2·27 at 7·0 µm	0·04	0·6 to 7·0 µm	—	—	Vacuum evaporation (quartz crucible with tungsten filament in contract with the charge)	Photo conductive cells; infra-red filters
3·05 in near infra-red	—	—	—	—	Vacuum evaporation (molybdenum boat)	—

(*Continued*)

TABLE 1 CHARACTERISTICS OF COATING MATERIALS

SL No.	SUBSTANCE	SYMBOL/ COMPOSITION	MASSIVE MATERIAL				
			Optical			Physical	
			Complex refractive index		Reflectance	Melting point °C	Density g/cm³ at 20°C
			Refractive Index at 0·589 µm	*Index of Absorption Region of Transparency**			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
53	Calcium fluoride	CaF_2	1·434 (crystal)	Range of transparency from < 150 nm to 15 µm	—	1 360	3·1
54	Calcium oxide	CaO	1·837	—	Diffuse reflecting power 85·4% for λ=0·6 µm	2 570	2·62
55	Calcium silicate	$CaO.SiO_2$	1·63	—	—	1 540	—
56	Cerium dioxide	CeO_2	—	—	—	1 950	7·3
57	Cerous fluoride	CeF_3	—	—	—	1 324	5·8
58	Cesium oxide	Cs_2O_3	—	—	—	400	4·25
59	Chromium oxide	Cr_2O_3	—	Spectral emissivity: Probable value 0·70 for range of observed value of 0·60 to 0·80 µm	Diffuse reflecting power 27% for λ=0·6 µm	2 440	5·21
60	Cryolite	Na_3AlF_6	1·36	Range of transparency from 200 nm to 10 µm	—	1 000	—
61	Gadolinium titanate	$Gd_2Ti_2O_7$	—	—	—	—	—

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FOR USE IN OPTICAL INSTRUMENT INDUSTRY — *Contd*

EVAPORATED MATERIAL				CHEMICAL DURABILITY	DEPOSITION TECHNIQUE	REPORTED APPLICATIONS
Optical			Physical Resistance to Abrasion on Glass Substrate†			
Complex refractive index at 0·546/0·589 µm*		Reflectance at 0·546 µm region of transparency*				
Refractive Index	*Extinction Coefficient*					
(9)	(10)	(11)	(12)	(13)	(14)	(15)
1·23 to 1·26 at 0·546 µm 1·37 to 1·4 at 0·589 µm	—	From 0·15 to 12·0 µm	Poor	Hygroscopic	Vacuum evaporation (molybdenum, tantalum boat)	Used in early work on antireflection coating of glass; transparent film in ultraviolet and infra-red region
—	—	—	—	—	—	—
1·68 at 0·60 µm and 1·71 at 0·44 µm	—	—	Good	Soluble in hydrochloric acid	Vacuum evaporation (tungsten boat or conical basket)	Base layer of double layer antireflection coating
2·2 at 0·54 µm on glass heated to 25°C and 2·4 on glass heated to 300°C	—	0·4 to 16·0 µm	Exceptionally good	Insoluble in dilute acids and water	Vacuum evaporation (tungsten boat, electron beam)	Beam splitter; used with magnesium fluoride films in multilayer high reflection and antireflection coatings
1·63 at 0·55 µ 1·59 at 2·0 µm	—	0·3 to >5·0 µm	—	—	Vacuum evaporation (tungsten boat, electron beam)	Multilayer coating
—	—	—	—	Soluble in acids	—	—
—	—	—	—	Insoluble in acids and alkalis	Vacuum evaporation (tungsten)	—
1·28 to 1·34	—	from 0·2 to > 14·0 µm	Poor	Hygroscopic	Vacuum evaporation (molybdenum boat)	Used in combination with zinc sulphide/cerium dioxide films for multilayer filter and high reflection coating; optically efficient antireflection film on glass
—	—	—	—	—	Vacuum evaporation (tungsten) using stoichiometric mixture of Gd_2O_3 and TiO_2	High reflecting mirrors in combination with lanthanum oxide for laser

(*Continued*)

TABLE 1 CHARACTERISTICS OF COATING MATERIALS

SL No.	SUBSTANCE	SYMBOL/ COMPOSITION	MASSIVE MATERIAL				
			Optical			Physical	
			Complex refractive index		Reflectance	Melting point °C	Density g/cm³ at 20°C
			Refractive Index at 0·589 µm	*Index of Absorption Region of Transparency**			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
62	Indium oxide	In_2O_3	—	—	—	—	7·17
63	a) Iron oxide	Fe_2O_3	—	Spectral emissivity: Probable value 0·70 for range 0·63 to 0·98 µm	Diffused reflecting power 26·3% for λ= 0·6 µm	1 565 (decomposes)	5·24
	b) Hematite	Fe_2O_3	3·46 at 0·546 µm			1 371	
	c) Magnatite	Fe_2O_3·	2·5 at 0·546 µm			1 457	
64	Mixture of iron oxide and calcium silicate	50% Fe_2O_3 50% CaO SiO_2	—	—	—	—	—
65	Lanthanum fluoride	LaF_3	—	—	—	—	—
66	Lanthanum oxide	La_2O_3	—	—	—	—	6·51
67	Lead chloride	$PbCl_2$	2·2 to 2·26	Range of transparency from 300 nm to > 14 µm	—	501	5·85
68	Lead fluoride	PbF_2	—	—	—	855	8·24
69	Lead oxide	PbO	2·51	—	—	888	9·53

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FOR USE IN OPTICAL INSTRUMENT INDUSTRY — *Contd*

EVAPORATED MATERIAL				CHEMICAL DURABILITY	DEPOSITION TECHNIQUE	REPORTED APPLICATIONS
Optical			Physical Resistance to Abrasion on Glass Substrate†			
Complex refractive index at 0·546/0·589 μm*		Reflectance at 0·546 μm region of transparency*				
Refractive Index	*Extinction Coefficient*					
(9)	(10)	(11)	(12)	(13)	(14)	(15)
—	—	—	Exceptionally good	—	Vacuum evaporation (platinum); reactive sputtering of indium in oxygen and argon gas atmosphere at 5×10^{-4} torr	Transparent electrically conducting glass window for aircraft and automobile
2·75 at 0·55 μm of reactively sputtered film	0·107 at 0·55 μm of reactively sputtered film	—	Exceptionally good	Not attacked except by hot hydrochloric acid or oxalic acid	Vacuum evaporation (tungsten); reactive sputtering of iron in oxygen and argon atmosphere at 5×10^{-4} torr	Beam splitters and infra-red interference films
2·0	—	—	Exceptionally good; film must be baked at 300°C to develop maximum hardness	Soluble in hydrochloric acid	Vacuum evaporation (tungsten)	Absorption filters and tinting of ophthalmic lenses
1·59 at 0·55 μm; 1·57 at 2·0 μm	—	0·22 to >2·0 μm	—	—	Vacuum evaporation (tungsten boat, molybdenum boat)	Multilayer coatings
1·95 at 0·55 μ; 1·86 at 2·0 μ	—	0·35 to >2·0 μm	Good	Insoluble in water but soluble in hydrochloric acid	Vacuum evaporation (tungsten boat)	High reflecting mirrors in combination with gadolinium titanate for lasers
2·3 at 0·55 μm; 2·0 at 10·0 μm	—	0·3 to 7·0 μm	—	Slightly soluble in dilute hydrochloric acid	Vacuum evaporation (platinum, molybdenum boat)	Beam splitters; infra-red transmitting film
1·75 at 0·55 μm; 1·70 at 1·0 μm	—	0·24 to >20·0 μm	Poor	—	Vacuum evaporation (platinum boat)	Protective coating for highly soluble optical crystals; multilayer coating in ultraviolet region in combination with magnesium fluoride/cryolite
—	—	—	—	Soluble in nitric acid and alkali	Can be sputtered	—

(*Continued*)

TABLE 1 CHARACTERISTICS OF COATING MATERIALS

SL No.	SUBSTANCE	SYMBOL/ COMPOSITION	MASSIVE MATERIAL				
			Optical			Physical	
			Complex refractive index		Reflectance	Melting point °C	Density g/cm^3 at 20°C
			Refractive Index at 0·589 μm	*Index of Absorption Region of Transparency**			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
70	Lead sulphide	PbS	4·2 (thin slices of crystals)	Range of transparency 3 μm	a) Varies from 40% to 48% for λ=0·24 to 0·35 μm b) Varies from 41% to 42% for λ=0·4 to 0·7 μm c) Varies from 35% to 31% for λ=1 to 11 μm	1 114	7·5
71	Lead telluride	PbTe	—	—	—	917	8·16
72	Lithium fluoride	LiF	1·39	Range of transparency from <110 nm to 10 μm	—	870	2·5
73	Magnesium aluminate	$MgOAl_2O_3$	1·72	—	—	2 135	3·6
74	Magnesium fluoride	MgF_2	1·38	Range of transparency from 230 nm to 10 μm	—	1 395	3·0
75	Manganese dioxide	MnO_2	—	—	—	>230	5·026
76	Molybdenum oxide	MoO_3	—	—	—	795	4·5
77	Neodymium fluoride	NdF_3	—	—	—	—	—
78	Neodymium oxide	Nd_2O_3	—	—	—	1 900	7·24
79	Nickel oxide	NiO	2·15	—	—	2·090	7·45

*For dielectric materials.

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FOR USE IN OPTICAL INSTRUMENT INDUSTRY — *Contd*

EVAPORATED MATERIAL				CHEMICAL DURABILITY	DEPOSITION TECHNIQUE	REPORTED APPLICATIONS
Optical			Physical Resistance to Abrasion on Glass Substrate†			
Complex refractive index at 0·546/0·589 µm*		Reflectance at 0·546 µm region of transparency*				
Refractive Index	*Extinction Coefficient*					
(9)	(10)	(11)	(12)	(13)	(14)	(15)
—	—	3·0 µm	Poor	Soluble in acids but not in potassium hydroxide	Vacuum evaporation (molybdenum)	Photodetectors
5·1 to 5·5	—	3·4 to 30·0 µm	—	—	Vacuum evaporation (tantalum boat)	—
1·36 at 0·546 µm	—	0·11 to 7·0 µm	Poor	Hydroscopic	Vacuum evaporation (electron beam, molybdenum and tantalum boat)	Antireflection coating
—	—	—	—	Slightly soluble in dilute hydrochloric acid	Vacuum evaporation (tungsten)	—
1·38 at 0·55 µm; 1·35 at 2·0 µm	—	0·21 to 10·0 µm	Exceptionally good	Not attacked by water or acids after baking at 300°C	Vacuum evaporation (electron beam, molybdenum, tantalum boat) at substrate temperature 250°C to 300°C	Most commonly used material for durable antireflection coating on glass; multilayer coating in combination with zinc sulphide or cerium dioxide; Fabry-Parot interference filters
—	—	—	—	Soluble in hydrochloric acid	Vacuum evaporation (tungsten)	—
—	—	—	—	Soluble in acids	—	—
1·60 at 0·55 µm; 1·58 at 2·0 µm	—	0·22 to >2·0 µm	Good	—	Vacuum evaporation (molybdenum, tungsten boat)	Multilayer coating
2·0 at 0·55 µm; 1·95 at 2·0 µm	—	0·4 to >2·0 µm	—	Soluble in hydrochloric acid; insoluble in water	Vacuum evaporation (tungsten boat)	—
2·18 at lithium line	—	—	Exceptionally good	Attacked by acids	Reactive sputtering of metal in an oxygen and argon atmosphere at 5×10^{-4} torr	Beam splitter

(*Continued*)

TABLE 1 CHARACTERISTICS OF COATING MATERIALS

SL No.	SUBSTANCE	SYMBOL/ COMPOSITION	MASSIVE MATERIAL				
			Optical			Physical	
			Complex refractive index		Reflectance	Melting point °C	Density g/cm³ at 20°C
			Refractive Index at 0·589 µm	*Index of Absorption Region of Transparency**			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
80	Platinum oxide	PtO_2	—	—	—	—	—
81	Silicon dioxide (Silica)	SiO_2	1·438 (For vitreous)	Range of transparancy from 200 nm to 5 µm	—	1 610 (decomposes)	—
82	Silicon monoxide	SiO	—	Range of transparency from 500 nm to 8 µm	—	—	—
83	Silver chloride	Agcl	2·071	—	—	455	5·56
84	Sodium fluoride	NaF	1·328	Range of transparency <250 nm	—	992	2·7
85	Tantalum pentaoxide	Ta_2O_5	—	—	—	1 470 (decomposes)	8·735
86	Tellurium oxide	TeO	—	—	—	Decomposed on heating	—
87	Thorium dioxide	ThO_2	2·2	Spectral emissivity: Probable value 0·50 for range of 0·20 µm to 0·57 µm	—	2 950	10·03
88	Thorium fluoride	ThF_4	—	—	—	—	—
89	Tin oxide	SnO_2	—	Range of transparency: >10 µm	—	Sublimates	—

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a) *Poor* — Removable on rubbing with a soft cloth.
b) *Good* — Withstand polishing and cleaning.
c) *Exceptionally Good* — Not removable by scratching with a steel pin.

FOR USE IN OPTICAL INSTRUMENT INDUSTRY — *Contd*

EVAPORATED MATERIAL				CHEMICAL DURABILITY	DEPOSITION TECHNIQUE	REPORTED APPLICATIONS
Optical			Physical Resistance to Abrasion on Glass Substrate†			
Complex refractive index at 0·546/0·589 µm*		Reflectance at 0·546 µm region of transparency*				
Refractive Index	*Extinction Coefficient*					
(9)	(10)	(11)	(12)	(13)	(14)	(15)
—	—	—	Good	Not attacked by hydrofluoric acid	Reactive sputtering of metal in an oxygen and argon atmosphere at 5×10^{-4} torr	Surface replica for electron microscopy
1·46 at 0·50 µm; 1·445 at 1·60 µm	—	0·20 to 8·0 µm	Exceptionally good	Very slightly soluble in alkalis	Slow vacuum evaporation (tungsten or tantalum boat, electron beam); reactive evaporation of silicon monoxide in oxygen atmosphere at 5×10^{-4} torr	Protection of front surface aluminium mirrors; interference films
1·45 to 1·9 (dependent on rate of evaporation and oxygen pressure)	—	0·50 to 8·0 µm	Exceptionally good	—	Vacuum evaporation (electron beam, tantalum or molybdenum boat)	Protection of front surface mirrors; interference films and surface replica for electron microscopy
—	—	—	Poor	—	Vacuum evaporation (molybdenum)	—
1·28 to 1·34	—	0·20 to 14·0 µm	Poor	Hygroscopic	Vacuum evaporation (tantalum, molybdenum boat)	Antireflection coating
2·84 at 0·31 µm; 2·42 at 0·80 µm for anodic film	—	—	Exceptionally good	—	Vacuum evaporation; anodic oxidation	Protecting glass surface against attack by alkalis
—	—	—	—	Soluble in hydrochloric acid and alkali	Can be sputtered	—
1·8 at 0·55 µ and 1·75 at 2·0 µ	—	from 0·25 to >2·0 µ	Exceptionally good	—	Vacuum evaporation (electron beam) at substrate temperature 200°C	Highly durable beam splitters and antireflection coating
1·52 at 0·40 µ	—	from 0·2 to >15·0 µ	Exceptionally good	—	Vacuum evaporation (tantalum boat)	Multilayer high reflection and antireflection coating
2·1 for vapour reactive film	—	—	Exceptionally good	Attacked by alkalis	Reactive sputtering of metal in oxygen and argon gas atmosphere at 5×10^{-4} torr; vapour reaction in air between tin halide and water vapour; vacuum evaporation (tungsten)	Transparent electrically conducting window glass for aircraft; antistatic coating on glass

(*Continued*)

TABLE 1 CHARACTERISTICS OF COATING MATERIALS

Sl No.	Substance	Symbol/ Composition	Massive Material				
			Optical			Physical	
			Complex refractive index		Reflectance	Melting point °C	Density g/cm³ at 20°C
			Refractive Index at 0·589 μm	*Index of Absorption Region of Transparency**			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
90	Titanium dioxide	TiO_2	2·54 to 2·71 (depending upon crystal structure)	—	—	1 640 to 1 850 (decomposes)	3·84 to 4·26
91	Titanium monoxide	TiO	—	—	—	—	—
92	Tungsten trioxide	WO_3	—	Range of transparency > 10 μm	—	1 473	7·16
93	Mixture of tungsten trioxide and aluminium oxide	$WO_3+Al_2O_3$	—	—	—	—	—
94	Uranium oxide	U_3O_8	—	—	—	2 700	7·31
95	Zinc selenide	ZnSe	—	—	—	>1 100	5·42
96	Zinc sulphide	ZnS	2·18 to 2·25	Range of transparency 400 nm to 14 μm	—	Sublimation	4·1
97	Zirconium dioxide	ZrO_2	2·13 to 2·20	Spectral emissivity: Probable value 0·40 for range 0·18 to 0·43 μm	Diffuse reflecting power 85·8% for $\lambda=0{\cdot}6$ μm	2 700	5·49

Note — The values in col 9, 10 and 11 are subject to slight variations depending upon the thickness, rate of deposition, purity of material, etc.

*For dielectric materials.

†Resistance to abrasion of the evaporated material on glass substrate is grouped in three categories as explained below:
a) *Poor* — Removable on rubbing with a soft cloth.
b) *Good* — Withstand polishing and cleaning.
c) *Exceptionally Good* — Not removable by scratching with a steel pin.

FOR USE IN OPTICAL INSTRUMENT INDUSTRY — *Contd*

EVAPORATED MATERIAL				CHEMICAL DURABILITY	DEPOSITION TECHNIQUE	REPORTED APPLICATIONS
Optical			Physical Resistance to Abrasion on Glass Substrate†			
Complex refractive index at 0·546/0·589 μm*		Reflectance at 0·546 μm region of transparency*				
Refractive Index	*Extinction Coefficient*					
(9)	(10)	(11)	(12)	(13)	(14)	(15)
2·2 to 2·7 at 0·55 μm (depending on structure)	—	0·35 to 12·0 μm	Exceptionally good	Marked resistance to salt water corrosion	Reactive sputtering of titanium/titanium monoxide in oxygen and argon atmosphere at 5×10^{-4} torr; heat oxidization of titanium film in air at 500°C; vacuum evaporation (electron beam)	Highly durable beam splitters; multilayer interference filters and protection of front surface aluminised mirrors
—	2·08 to 2·32 (dependent upon rate of evaporation and oxygen pressure)	—	Exceptionally good	—	Slow vacuum evaporation in oxidized atmosphere at 5×10^{-4} torr (tungsten boat)	Beam splitter; multilayer interference filter
2·0 for evaporated and reactively sputtered film	—	Visible to > 10·0 μm	Good	Attacked by hot alkalis but not by acids except hydrofluoric	Vacuum evaporation (platinum)	Shadow casting for electron microscopy
—	—	—	Exceptionally good	—	Vacuum evaporation (tungsten)	Absorption filter of low reflectivity
—	—	—	—	—	Vacuum evaporation (tungsten)	Shadow casting for electron microscopy
2·58 at 0·633 μm	—	0·6 to >5·0 μm	Good	—	Vacuum evaporation (molybdenum or platinum boat)	Laser and mirrors; infra-red filters
2·35 at 0·55 μm; 2·2 at 2·0 μm	—	0·38 to approx 25·0 μm	Poor	Hygroscopic	Vacuum evaporation (molybdenum or tantalum boat)	Beam splitters; multilayer interference filters and high reflection coating in combination with magnesium fluoride or cryolite
2·1 at 0·55 μm; 2·0 at 2·8 μm	—	—	Exceptionally good	—	Vacuum evaporation (electron beam, tungsten boat) at substrate temperature 200°C	—

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1957-1961	Prismatic compasses, non-liquid
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